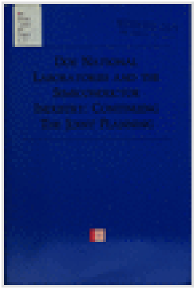

DOE National Laboratories and the Semiconductor Industry: Continuing the Joint Planning: Report on a Workshop (1987)

Manufacturing Studies Board; National Materials Advisory Board; Commission on Engineering and Technical Systems; National Research Council

Pages
38

Size
5 x 9

ISBN
0309311330

DOE National Laboratories and the Semiconductor Industry: Continuing the Joint Planning

Report on a Workshop

Manufacturing Studies Board and
National Materials Advisory Board
Commission on Engineering and Technical Systems
National Research Council

NATIONAL ACADEMY PRESS
Washington, D.C. 1987

NOTICE: The project that is the subject of this report was approved by the Governing Board of the National Research Council, whose members are drawn from the councils of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine. The members of the committee responsible for the report were chosen for their special competences and with regard for appropriate balance.

This report has been reviewed by a group other than the authors according to procedures approved by a Report Review Committee consisting of members of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

The National Academy of Sciences is a private, nonprofit, self-perpetuating society of distinguished scholars engaged in scientific and engineering research, dedicated to the furtherance of science and technology and to their use for the general welfare. Upon the authority of the charter granted to it by the Congress in 1863, the Academy has a mandate that requires it to advise the federal government on scientific and technology matters. Dr. Frank Press is president of the National Academy of Sciences.

The National Academy of Engineering was established in 1964, under the charter of the National Academy of Sciences, as a parallel organisation of outstanding engineers. It is autonomous in its administration and in the selection of its members, sharing with the National Academy of Sciences the responsibility for advising the federal government. The National Academy of Engineering also sponsors engineering programs aimed at meeting national needs, encourages education and research, and recognises the superior achievements of engineers. Dr. Robert M. White is president of the National Academy of Engineering.

The Institute of Medicine was established in 1970 by the National Academy of Sciences to secure the services of eminent members of appropriate professions in the examination of policy matters pertaining to the health of the public. The Institute acts under the responsibility given to the National Academy of Sciences by its congressional charter to be an adviser to the federal government and, upon its own initiative, to identify issues of medical care, research, and education. Dr. Samuel O. Thier is president of the Institute of Medicine.

The National Research Council was organised by the National Academy of Sciences in 1916 to associate the broad community of science and technology with the Academy's purposes of furthering knowledge and advising the federal government. Functioning in accordance with general policies determined by the Academy, the Council has become the principal operating agency of both the National Academy of Sciences and the National Academy of Engineering in providing services to the government, the public, and the scientific and engineering communities. The Council is administered jointly by both Academies and the Institute of Medicine. Dr. Frank Press and Robert M. White are chairman and vice-chairman, respectively, of the National Research Council.

This project was supported by the Academy Industry Program.

Available from:
National Academy Press
2101 Constitution Avenue, N.W.
Washington, DC 20418

Printed in the United States of America

STEERING GROUP FOR THE WORKSHOP ON THE SEMICONDUCTOR INDUSTRY AND THE NATIONAL LABORATORIES

LARRY W. SUMNEY (*Chairman*), President, Semiconductor Research Corporation

WILLIAM F. BRINKMAN, Executive Director for Research, Physics Division, AT&T Bell Laboratories

W. DALE COMPTON, Senior Fellow, National Academy of Engineering

BERNARD H. KEAR, State of New Jersey Professor of Materials Science and Technology, and Director, Center for Materials Synthesis, College of Engineering, Rutgers University

JAMES C. McGRODDY, Assistant Group Executive for Technology, Information Systems Technology Group, IBM Corporation

MARTIN J. McHALE, Vice-President and General Manager, Maintenance Services, Control Data Corporation

JOHN A. WHITE, Regents' Professor, Industrial and Systems Engineering, and Director, Material Handling Research Center, Georgia Institute of Technology

EDWIN M. ZIMMERMAN, Member of the Bar, District of Columbia

NATIONAL MATERIALS ADVISORY BOARD

JOHN P. RIGGS, Executive Director of Technology, Celanese Research Corporation
WILLIAM P. SLICHTER, Executive Director (retired), Research Materials Science and Engineering Division, AT&T Bell Laboratories
JOHN E. TILTON, Coulter Professor, Department of Mineral Economics, Colorado School of Mines
JAMES C. WILLIAMS, Dean, Carnegie Institute of Technology, Carnegie-Mellon University

STAFF

GEORGE H. KUPER, *Director*, Manufacturing Studies Board
KERSTIN B. POLLACK, *Director*, Program Development, Manufacturing Studies Board
THOMAS C. MAHONEY, *Staff Officer*, Manufacturing Studies Board
VERNA J. BOWEN, *Administrative Assistant*

Contents

Executive Summary

The extensive capabilities, expertise, and existing activities of the national laboratories of the U.S. Department of Energy (DOE) could make a significant contribution to the technical needs of the U.S. semiconductor industry. Although the laboratories have a variety of programs to make their facilities and research results available to industry, they are generally ad hoc, uncoordinated, and tied to individual companies. A comprehensive strategy is needed to identify and aggregate industry's needs, to establish effective modes of cooperation with industry as a whole, and to channel relevant activities of the laboratories to address these needs more effectively. The necessary steps to develop such a strategy were outlined in a recent National Research Council report, *The Semiconductor Industry and the National Laboratories: Part of a National Strategy*, available from the National Academy Press.

An important step identified in that report is that of initiating a technical dialogue between the national laboratories and the appropriate industry representatives. At a workshop held from May 26 to 28, 1987, at Sandia National Laboratories, representatives of the national laboratories and the semiconductor industry identified a broad range of specific technical areas for collaborative research. These technologies can be grouped in the following categories:

- patterning and metrology;
- interconnects and packaging;
- thin films and pattern transfer;
- reliability, failure, and yield analysis;
- compound semiconductors; and
- automation and facilities.

In each category, specific industry needs were identified and the laboratories with the most advanced capabilities in each technology were named to lead potential collaborative research programs.

In addition to general collaborative research programs in each of these technical areas, several specific research initiatives were recommended by the workshop participants. A discussion of these initiatives follows.

X-RAY LITHOGRAPHY

- In the area of x-ray mask distortion, both the Sandia and Brookhaven National Laboratories have research programs investigating x-ray mask materials for sources of distortion. Workshop participants recommended that these laboratories pursue a cooperative program with corporations such as IBM and Perkin-Elmer. This cooperative effort should be funded at a level of $20 million per year for 5 years to allow sufficient resources for rapid progress.
- Sandia has conducted extensive research on radiation damage to integrated circuits. A cooperative research program with a commercial chip producer would introduce commercial priorities to the work being conducted at Sandia and would speed progress in improving the reliability of devices produced using x-ray lithography.

MANUFACTURING

The ability to mass-produce chips with quarter-micron line widths will be essential to future semiconductor competitiveness. New manufacturing processes will need to be developed and scaled-up, and orders-of-magnitude improvements will be needed in process reliability, repeatability, and cleanliness. Workshop participants recommended that the new radiation-hardened integrated circuit (RHIC-II) clean room facility at Sandia be made the focal point for a National Center for Ultraclean Manufacturing Research. This facility could also be used to conduct manufacturing process research using a modular manufacturing approach. New process modules could be integrated into the fabrication line and tested in an ultraclean manufacturing environment. Such a facility would provide a crucial element for industry's efforts to develop mass production techniques for quarter-micron structures.

CONTINUING DIALOGUE

• The national laboratories should organize a series of workshops on specific technologies that are appropriate for collaborative research. Research problems could be identified with attention to areas of synergy with DOE's mission and program goals; the participants who should be involved could be determined; and research plans, funding, schedules, and other logistical details decided to allow rapid project initiation.

• Alternatively, representatives from national laboratories could visit industrial plants to build consensus on specific industrial needs and potential laboratory contributions. At the same time, industrial representatives would visit laboratory facilities to determine their capabilities and potential contributions. A single workshop could then be held to address the logistical details necessary to begin selective, coordinated collaborative research projects.

This workshop was successful in identifying a number of specific research topics suitable for future collaborative research between the semiconductor industry and the national laboratories. As the earlier report emphasized, a successful strategy to mobilize the resources of the national laboratories to benefit the long-term competitiveness of the U.S. semiconductor industry will require resolution of a range of difficult issues. Publication and ownership of results, foreign participation and access, technology transfer mechanisms, financial costs and benefits, scheduling, the effect of commercial needs on laboratory program priorities, and the treatment of competitive businesses are examples of the complex issues that must be resolved to create an effective strategy. This workshop demonstrated that linkages exist between industry's technical

needs and the national laboratories' capabilities. Strong commitment and leadership within the semiconductor industry and the DOE will be necessary to make this potential a reality.

1
Introduction

A workshop, "The Semiconductor Industry and the National Laboratories," held at the National Academy of Sciences on February 24, 1987 (subsequently referred to as the first workshop), established that the national laboratories operated for the U.S. Department of Energy (DOE) have extensive facilities and capabilities that, if properly utilized, could be of significant benefit to the semiconductor industry.* The workshop participants agreed that the DOE laboratories should, through further dialogue with the semiconductor industry, initiate the technical planning process to define unique missions and modes of interaction with industry that will assure timely and relevant contributions to the nation's semiconductor technology. Current policies and practices of the national laboratories have been effective in fostering better interaction with a variety of industries, and technology transfer is now an active part of the laboratories' mission. However, achieving the large-scale collaboration with the semiconductor industry envisioned by the workshop participants will require a much better

*A report of the workshop, *The Semiconductor Industry and the National Laboratories: Part of a National Strategy*, is available from the National Academy Press.

understanding by both industry and the laboratories of their respective capabilities, research priorities, and constraints. In addition, specific issues, such as publication and ownership of results, foreign participation and access, transfer mechanisms, financial effects, cost sharing, time and result expectations, the level of involvement of industry in the establishment of laboratory program priorities, and treatment of competitive businesses need to be resolved if collaborative activities are to be successful.

To continue the planning of joint research and development (R&D) projects and further address the issues raised at the February 1987 workshop, a second workshop was held from May 26 to 28, 1987, at Sandia National Laboratories. The purpose of this meeting was to identify specific areas of research needed by the semiconductor industry and to identify where research capabilities exist within the national laboratories to address these needs. The workshop discussions were designed to inform industry representatives of relevant existing projects and expertise in the laboratories; to inform DOE representatives of the industry's R&D agenda and priorities; to identify desirable joint laboratory/industry R&D projects and programs that could be pursued; to explore alternative approaches for industry sponsorship of joint R&D projects on both an individual and multicompany basis; and to propose mechanisms for effective sharing of expertise and technology transfer.

The workshop was structured to convey information about the capabilities of the national laboratories and the technical needs of the industry, and to build consensus on the most promising areas of future cooperation. The capabilities of the laboratories were effectively portrayed in poster sessions in which each laboratory organized a display of its activities in the semiconductor area; a representative from each laboratory was available to answer questions. The poster sessions were complemented by a series of presentations given by each of the laboratories that emphasized current projects, facilities, and expertise relevant to semiconductor development. After these sessions, industry representatives described R&D priorities and technology forecasts in each of the following areas: ultra-large scale integrated (ULSI) circuit design, patterning, interconnects, packaging, manufacturing, reliability, compound semiconductors, advanced process technology, and metrology. Finally, small groups of laboratory and industry representatives discussed possible joint research efforts on specific aspects of each of these technologies.

The balance of this report describes the findings of these small group sessions, as well as possible mechanisms for furthering cooperative projects. (The topics and speakers are listed in the Appendix.)

2
Group Reports

Working groups were convened in the following areas:

- patterning and metrology;
- interconnects and packaging;
- thin films and pattern transfer;
- reliability, failure, and yield analysis;
- compound semiconductors; and
- automation and facilities.

I. PATTERNING AND METROLOGY

The group discussed possible collaborative efforts in the areas of x-ray and optical lithography. The gap is narrowing between the practical pattern resolution that is obtainable with x rays compared with near-ultraviolet (UV) excimer lasers. It is believed that excimer laser-based lithographic systems will achieve about 0.3-micron resolution and will be production-line certified by the early 1990s. X-ray lithography is limited by Fresnel diffraction to about 0.2-microns when the mask-to-wafer spacing is limited to a practical value. Contact printing is probably not feasible for high-volume production because of mask damage problems and the time needed to assess damage on fine-line masks. Some industrial representatives suggested that the "window" for x-ray lithography in large-volume production may close because of improvements in optical lithography and resist technology.

X-Ray Lithography

A major stumbling block to the implementation of x-ray lithography systems is mask distortion. Although x-ray masks have been in development for about 10 years and many subcritical studies have been done, the level of activity in terms of both research and production volumes has been too low to engender much success in eliminating the causes of distortion. A major continuing program is necessary to establish a viable mask production capability to reduce the distortion of substrates and defect densities. Basic studies of the mechanisms that cause substrate membrane distortions and development of patterning processes that do not introduce strain could benefit from the capabilities of the national laboratories. Both Sandia and Brookhaven have programs to examine x-ray mask materials for sources of distortion. The group considered that a cooperative program, including IBM and Perkin-Elmer, would be a potentially effective means to speed progress on x-ray mask distortion. A funding level of about $20 million per year for 5 years was proposed by the group as being necessary to ensure rapid progress.

Work on x-ray masks should also be extended to address the problem of radiation damage. Most mask materials currently in use darken faster than predicted, drastically reducing their useful life. Again, Sandia and Brookhaven have been working on this problem, as have IBM and the Microelectronics Center of North Carolina (MCNC).

A second major stumbling block to the implementation of x-ray lithography is a suitable x-ray source. Most members of the group supported continuation of planning studies for construction of a dedicated synchrotron and support facilities at Brookhaven, but many expressed reservations about committing to construction before the alternatives have been fully explored. A listing of the unresolved issues follows.

- X-ray mask distortion is a major deficiency, as discussed above.

- The rapidly evolving deep-UV sources, free-electron lasers, and nonlinear wavelength conversion of solid-state lasers are attractive alternatives to synchrotron sources for sub-0.3-micron lithography.
- Very few U.S. companies need the patterning throughput offered by a synchrotron. In addition, compact synchrotrons that might be affordable to smaller companies may not be possible.
- Alternative x-ray sources, such as plasma, may offer lower production costs per wafer, especially for most U.S. companies.
- Committing to such a costly facility at this time may severely limit the ability of the industry and research communities in the United States to afford to explore attractive options.

Research is needed to determine the extent and effects of x-ray radiation during the lithographic process on device reliability. Sandia has conducted extensive studies on radiation damage through its radiation-hardened integrated circuit (RHIC) program for the military, and the facilities at Sandia for this type of research are unequaled. A cooperative research program with a commercial chip producer would both improve commercial access to Sandia's knowledge and help researchers there gain a better understanding of commercial priorities in this area.

For x-ray lithography to become commercially viable in a mass production context, additional research will be needed on the total lithographic system. Step and repeat aligners will be required for beam line exposure; alignment marks must be recognized and registered to improve accuracy; mask inspection will be critical as line widths reach the quarter micron level; and defect correction will be increasingly difficult at quarter-micron resolutions. Equipment makers are refining and improving current methods to meet these needs, but progress is slow. The group suggested that alternate approaches to solving these problems could usefully be pursued by the relevant national laboratories in collaboration with industry.

Optical Lithography

Although members of the group strongly encouraged continued research in x-ray lithography, they viewed optical lithography, using deep-UV light, as the dominant technology for resolution down to about 0.3-micron. Progress will be needed in a number of areas to fulfill this potential. For example, different resists with good dry-etch resistance, good contrast, and vertical wall profiles are required for each of the UV wavelengths proposed for lithography. Sandia has been active in resist development and two different classes of resists resulting from research there have been commercialized: a dyed resist for metal-level patterning at visible wavelengths, and self-developing polysilane resists for use with UV, deep-UV, and x-ray exposure wavelengths.

Improvements in the usable lifetimes and reliability of excimer lasers are essential for their commercial use; both Los Alamos and Sandia have excellent programs in excimer lasers.

Another area needing research is free electron lasers, which are a possible source for deep-UV systems. Reflective masks, reflective optics, and low-absorption thin resists are needed to make such systems viable. Another possible area for technology development is deep-UV sources using diode-pumped solid-state lasers with frequency-up conversion using optical nonlinear techniques. Sandia, Los Alamos, American Telephone and Telegraph (AT&T), and Perkin-Elmer were identified by the group as appropriate members of a possible collaborative research effort in these laser technologies.

The group recognized the importance of further refinements in ion-beam technologies. Sandia's experience and computational capabilities in the ion-beam inertial fusion program make it well-suited to explore this option.

II. INTERCONNECTS AND PACKAGING

The group identified a number of programs having high potential for an effective collaborative effort between the national laboratories and industry.

Laser-Assisted Deposition

Laser-assisted deposition and removal of metals and insulators was identified as an area of high significance needing extensive R&D work. Initial application of the technology could be for programmable connections, customizing, chip repair, and rapid prototyping. However, a better understanding of the process—particularly process control—and further equipment development is needed before extensive use of this technology in industry is feasible. Although several laboratories have laser and analytical facilities, the group identified Lawrence Livermore as the lead laboratory; Sandia also has extensive experience and capabilities in this area. Potential industrial partners include General Electric, National Semiconductor, Honeywell, Texas Instruments, and equipment suppliers such as Perkin-Elmer and GCA.

Low-Pressure Chemical Vapor Deposition (LPCVD)

Research is needed in microwave plasma-assisted LPCVD of metals, insulators, and semiconductors to achieve lower temperatures, better adhesion, and better damage control. Lawrence Berkeley laboratory has programs in this area.

Protective Overcoats

An effective collaborative program in protective overcoats would include work on new materials, such as diamond, new deposition techniques, interfacial studies, and compatibility with polymers. Sandia has mature research programs in this area. A number of universities, including Cornell and Lehigh, that have programs in this area should be included in any collaborative program between the national laboratories and industry.

Thermofluid and Thermomechanical Modeling

Research is needed to construct better data bases for specific materials properties and to provide tools for simulating thermal properties of complex material systems. The national laboratories have expertise both in constructing thermal models and in performing materials characterization, and they have the computer resources, including supercomputers, necessary for effective modeling efforts. Industrial partners in a prospective collaborative program include National Semiconductor and Control Data Corporation, which has been sponsoring work in this area at the University of Arizona. IBM also has strong capabilities in this area.

Optical Interconnects

Research in a number of areas is needed to advance the state of the art in optical systems. In particular, the group identified the need for research in fiber-optic couplers and optical receivers and transmitters on chips, using gallium arsenide on silicon or germanium. Both Ames and Sandia have existing programs in optoelectronics, and the technology is of clear long-term interest to the industry. The group deferred suggesting industry partners pending further discussion within the industry.

Noncontact Testing

As device sizes decrease noncontact (beam) testing of wafers and complex chips will increasingly be a necessity to avoid chip damage and contamination and to improve throughput; this need applies equally to compound semiconductors. Los Alamos has existing facilities and techniques for measuring transient response, on-wafer, of gallium arsenide devices and circuits. Hughes Aircraft and Rockwell already have informal programs in on-chip, high-speed testing of compound semiconductors that could benefit from national laboratory expertise.

Ceramic Materials

New ceramic materials and processes for multilayer packages and substrates are a key development needed by industry and one in which the national laboratories, especially Oak Ridge, have demonstrated expertise.

III. THIN FILMS AND PATTERN TRANSFER

The group identified industry interests in this area as being ionized cluster beam and sputter deposition, laser- (excimer) assisted chemical vapor deposition (CVD), and plasma CVD. The national laboratories have programs in each of these areas and understand the broad concepts, but they need a better understanding of specific industrial problems and applications in each area. Opportunities for laboratory contributions to thin film deposition and pattern transfer through collaborative programs include:

- low-temperature processing, including epitaxy, thin oxides, interlayer dielectrics, and metal interconnects;
- improved process reliability as the number of process steps increases to obtain improved yields, greater throughput, and reduced equipment downtime;

- uniformity and mechanical integrity of the films;
- deposition and etching technologies for quarter micron structures;
- metrology; and
- improved process analysis techniques with feedback to process development.

Success in processing requires better understanding of the basic physical and chemical behavior of the materials and processes being used. The necessary research is a strength of the national laboratories; collaborative projects could be devoted to identifying industry's research priorities, developing processing techniques based on the research results, and applying the techniques to specific processes. A modular manufacturing concept could be an effective mechanism for accomplishing the necessary process development. With Sandia as the lead laboratory, a joint fabrication line could be established with industry to develop machine and process integration techniques. Modules for the line would be developed at the laboratories based on research results, then modified and integrated into the fabrication line. The modular manufacturing concept and joint fabrication line would be an effective mechanism for successful collaboration in many of the relevant areas.

IV. RELIABILITY, FAILURE, AND YIELD ANALYSIS

The group identified opportunities for the national laboratories in developing improved surface/material characterization and analysis techniques, especially for on-line process diagnostics and failure analysis. The laboratories already have advanced capabilities in this area, which could be modified if necessary and applied to industrial problems. Development of new techniques applicable to sub-micron circuit production should also be pursued by the national laboratories. Because of the expertise of the national laboratories in this area and the urgent need in industry, the group expressed a strong consensus that a dialogue between industry and the laboratories should begin now to define specific projects and to examine potential mechanisms for collaboration. Dissemination of the laboratories' current capabilities should begin immediately, possibly with the help of the Semiconductor Research Corporation (SRC). The next step would be to initiate projects between individual companies and laboratories, leading to coordinated, industry-wide programs.

V. COMPOUND SEMICONDUCTORS

The group identified a number of possible collaborative programs.

Improved Substrates

For certain special applications, higher costs of gallium arsenide and other compound semiconductors are not a problem, but for a larger market to emerge the costs will need to fall. Development of lower cost material, improved substrates, and bulk materials in gallium arsenide is a clear need. The DOE laboratories have experience in materials growth (Bridgeman and liquid crystal epitaxy), theory, and simulations, as well as extensive capabilities in structural, optical, electronic, and paramagnetic materials defect analysis and impurity characterization. Potential industry partners include compound semiconductor crystal/substrate vendors (e.g., Litton, Crystal Specialties), device companies (e.g., Vitesse, Gigabit, Hewlett-Packard), and defense contractors (e.g., Rockwell, Hughes, AT&T, TRW, Honeywell, and Texas Instruments).

Epitaxial Materials

Improved, lower cost epitaxial materials are needed in gallium arsenide and other III-V compound semiconductors. The DOE laboratories, particularly Sandia, Lawrence Berkeley, the Solar Energy Research Institute (SERI), and Ames, have experience in a variety of applicable technologies, including molecular beam epitaxy; metallo-organic chemical vapor deposition (MOCVD); beam-assisted epitaxial growth; structural, optical, electronic, and microscopic characterization; theoretical modeling; and device fabrication. The group listed several potential industry partners, including Rockwell, Hewlett-Packard, AT&T, Honeywell, TRW, and Texas Instruments.

Point-Defect Reduction

The development of capabilities for on-line monitoring of point defects in compound semiconductors is essential for point-defect reduction. The national laboratories have established capability in point-defect characterization. Sandia, Lawrence Berkeley, and Ames have done work in the correlation of device performance and defect type and concentration. These activities are closely related to other work on materials development and characterization. Continued fundamental research in this area would be of benefit to all industrial compound semiconductor manufacturers.

Modeling

Modeling of solid-state physics, electronic properties, and device characteristics was identified as a crucial need in all types of semiconductor technologies. The need is particularly acute in compound semiconductors because the electronic band structure is engineered for novel transport properties. As a result, models and codes developed for silicon devices are not applicable. The national laboratories have experience in modeling techniques and have the facilities necessary to conduct experiments in solid-state physics and materials science to tailor band structures. They also have access to the necessary computer power. These capabilities would be useful to all semiconductor manufacturers.

VI. AUTOMATION AND FACILITIES

The group identified a variety of areas in which the laboratories have expertise that would be useful to industry.

Ultraclean Manufacturing

Semiconductor manufacturers expect that cleanliness control will need to improve by four orders of magnitude over the next decade if U.S. manufacturers are to achieve competitive production of ULSI semiconductors. Such an improvement over current capabilities will require a better understanding of clean environments, including analysis, measurement, and evaluation. The new class one clean room facility constructed at Sandia for its RHIC-II program has the potential to make a major contribution in the understanding of clean environments. It contains 22 separate clean rooms allowing a multitude of discrete simultaneous experiments. The group suggested that this facility could provide the basis for a National Center for Ultraclean Manufacturing Research that would perform research on clean environments using a total system approach. Additional expertise developed at Oak Ridge, Argonne, Ames, and Lawrence Berkeley laboratories would also be a valuable contribution. Every semiconductor manufacturer would be interested in such an effort, particularly if research were to focus on generic industrial problems and the results could be applied to a variety of processes and factory situations.

Modeling and Simulation

The drive for mass production of ULSI chips is rapidly creating a need for better modeling and simulation capabilities. Current two-dimensional modeling techniques are improving, but much progress is needed in three-dimensional modeling. Simulation of device and circuit behavior, based on reasonably accurate models will be a crucial part of new semiconductor design and production. Process modeling and simulation are also becoming more important as the requirements of ULSI production advance, incorporating automated processes with closed-loop control. The national laboratories have the necessary supercomputing power and software expertise to make advances in this area. The group suggested that Los Alamos or Lawrence Livermore might be appropriate lead laboratories for collaborative projects with industry.

Analytical Diagnostics and Tools

Collaborative projects in this area might focus on development of automated analysis software, three-dimensional profiling, defect location and identification, environmental analysis, and ultra-trace analysis. Advanced software for data analysis and compression would also be useful. Argonne, Los Alamos, Sandia, and Lawrence Berkeley were noted as having valuable experience in this area.

Automation and Control

Advances are needed in both hardware and software, with an emphasis on eliminating sources of defects and contamination from the manufacturing process, minimizing the downtime of expensive process equipment, and maintaining control of the process for improved reliability and high yields. Specific technologies that are needed include process integration, expert systems, improved sensors, automated process control with adaptive feedback, and flexibility for process modification and rapid changes in the production mix. The group recognized the relevance to semiconductor manufacturing of many of the technologies developed for the Automated Manufacturing Research Facility (AMRF) at the National Bureau of Standards. It was suggested that Sandia might be the appropriate lead laboratory for a collaborative effort in this area, with substantial input from the researchers at the AMRF.

Advanced Processing Technologies

Although the members of the group did not pursue this topic in detail, they did identify laser-enhanced processing, ion-beam technologies, and microwave plasma CVD as specific process technologies in which the national laboratories have demonstrated expertise. Potential collaborative efforts should focus on R&D of improved techniques and equipment. Oak Ridge was suggested as a possible lead laboratory for such collaboration.

Materials

Better understanding of existing materials and the development of new materials for semiconductor production are increasingly important to advances in ULSI chip production. The national laboratories have a long history in materials research; that expertise should quickly and effectively be applied to the specific needs of the semiconductor industry. Areas such as ceramics, glass, resists, polymers, dielectrics, compound semiconductor materials, and superconductors would benefit from continued work by the national laboratories. Because virtually all of the laboratories have programs in materials, the group did not suggest a lead laboratory for any potential collaborative projects.

3
Conclusions

When the full workshop reconvened, it was apparent to all that many specific areas could be easily identified in which the expertise and capabilities of the national laboratories would be extremely beneficial to the semiconductor industry. The discussion then turned to the next steps needed to initiate activity in the many areas identified by the smaller discussion groups. A variety of mechanisms were endorsed for pursuing future collaborative efforts.

- The laboratories already have some interaction with industry through their user facilities, cost-reimbursable contract research, personnel exchanges, and technology transfer offices. Such activities, between individual laboratories and single companies, will continue to be effective means for maximizing the utility of national laboratory resources, accomplishing technology transfer, and keeping the laboratories current on industrial problems. Recent legislation (e.g., the Federal Technology Transfer Act of 1986) and policy initiatives have created much needed flexibility in the types of cooperative activities that the laboratories could pursue with industrial companies.
- Augmentation of current interactions is required. A broad, coordinated program between the semiconductor industry in general, including materials and equipment suppliers, hardware and

software vendors, and manufacturers, and the national laboratories as a group is necessary to ensure full coverage of relevant research topics, to avoid redundancy, and to apply the total resources of the national laboratories to generic industrial problems. The participants discussed the possibility of forming a Task Force on Semiconductors within the DOE* to interface with industrial representatives, match research needs with the appropriate laboratories, and coordinate the entire activity to maximize effectiveness. The need for an analogous body for the industry was recognized and recommended. The workshop participants debated the possibility of coordinating any collaboration with the national laboratories through SEMATECH, the Semiconductor Research Corporation, or some other body specifically formed for the task. No specific conclusions were reached.

• Information exchange remains a major barrier to effective collaboration. Two ways of beginning to overcome this handicap were discussed:

1. A series of workshops could be held, at the initiative of the national laboratories, on the specific technologies and research topics identified as promising areas for future collaboration. The specific subjects were identified by the discussion groups: deep-UV photolithography, ultraclean manufacturing, laser processing, metrology, plasma etching and deposition, analytical methods, process modeling, automation, III-V materials/devices, and failure analysis. Funding, sponsorship, attendees, and location were noted as issues to be addressed.

2. Representatives from the national laboratories could visit industrial plants to gain a better understanding of the processes, instruments, techniques, and analyses used by industry; the constraints, problems, and priorities facing manufacturers in a mass production environment; and the relevance of the laboratories' facilities and research to these industrial conditions. A series of such site visits would provide access to more industrial people than a workshop would and give the laboratory representatives a better feel for individual company differences. The site visit teams would be responsible for building the consensus about specific industrial needs and potential laboratory contributions, which could

---

*Subsequent to the meeting, such a Task Force was formed within the DOE, consisting of a representative from each laboratory.

be confirmed by a single large workshop of laboratory and industry representatives. At the same time as the laboratory personnel are visiting industry, teams of industry representatives could visit the laboratories to get firsthand exposure to their facilities and capabilities. Each of these teams would then write a series of white papers for distribution within the industry and DOE detailing the capabilities of the laboratories and providing the names of contacts. Again, a single workshop could facilitate additional contacts, answer questions, and help coordinate responses.

- The workshop participants suggested that an initiative be taken to explore ways to make the RHIC-II clean room facility at Sandia the focal point for a National Center for Ultraclean Manufacturing Research. (An analogous facility is in operation at the Tohoku University in Japan.) This facility might also be used to conduct research in machine and process integration techniques using a modular manufacturing approach. To be competitive in future ULSI production, cleanliness levels will need to improve dramatically; the United States must have the capability to conduct research on the total system of ultraclean manufacturing environments. Including process integration research in such a facility demonstrates the recognition that effective process integration will be essential to the success of the ultraclean manufacturing system. The group recognized that such an initiative would require the full support of both the industry and the DOE.

In conclusion, this second workshop for the semiconductor industry and the national laboratories identified a number of specific research topics suitable for future collaborative projects. Sufficient enthusiasm was generated in some instances that companies are independently initiating further discussions with the laboratories to explore new projects. Such initiatives demonstrate the relevance of the national laboratories' activities to the needs of industry and improve the outlook for the success of a broad cooperative program that could better mobilize the laboratories' resources.

If the necessary broad-based program of collaborative activities is to be successful, specific issues, such as publication and ownership of results, foreign participation and access, transfer mechanisms, financial effects, cost sharing, time and result expectations, industry's level of involvement in the establishment of laboratory program priorities, and treatment of competitive businesses, must be resolved. As the report of the first workshop of

February 24, 1987, emphasized, resolution of these issues demands a commitment on the part of both government and industry to remove existing impediments to progress. This report has made clear that many technical opportunities exist for beneficial collaboration between the semiconductor industry and the national laboratories. Strong leadership in the context of a well-defined national strategy for a competitive semiconductor industry is needed to ensure that these opportunities are grasped.

Appendix
Workshop Registrants

CHARLES W. ALLEN, Argonne National Laboratory
L. K. ANDERSON, Sandia National Laboratories
BILL R. APPLETON, Director, Solid-State Division, Oak Ridge National Laboratory
FRANCES P. ARMIGO, Sandia National Laboratories
D. E. ARVIZU, Sandia National Laboratories
R. BAIR, Sandia National Laboratories
W. BAUER, Sandia National Laboratories
IAN BELL, National Semiconductor Corporation
JOHN BENNER, Program Manager, High-Efficency Program, Solar Energy Research Institute
HERBERT BENNETT, Senior Scientist, Semiconductor Electronics Division, National Bureau of Standards
VERNA J. BOWEN, Administrative Assistant, Manufacturing Studies Board, National Research Council
CHARLES T. BRODNAX, E-Systems, Incorporated, Garland Division
STEVE BRUECK, Center for High-Technology Materials, University of New Mexico
ROBERT A. BURMEISTER, Director, Materials Research Laboratory, Hewlett-Packard Company

ROBERT BYRNE, Senior Engineering Manager, National Semiconductor Corporation
ROLAND CANNON, Staff Scientist, Lawrence Berkeley Laboratory
JOHN R. CARRUTHERS, Intel Corporation
GREG G. CHEN, Technology Director, Microelectronics, Eaton Corporation
W. DALE COMPTON, Senior Fellow, National Academy of Engineering
BEB CRAFT, Physicist, X-Ray Ring Manager, National Synchrotron Light Source, Brookhaven National Laboratory
JAMES M. DAUGHTON, Vice-President, Corporate Solid-State Laboratory, Honeywell Incorporated
RICHARD C. DEHMEL, Chairman, Components Production, Strategic Capabilities Segment, Intel Corporation
B. L. DOYLE, Sandia National Laboratories
P. J. EICKER, Sandia National Laboratories
FUNG-SUN FEI, Hewlett-Packard Company
JOSEPH F. FIGUEIRA, Los Alamos National Laboratory
GERHARD A. FRANZ, General Electric Company
J. B. GERRARDO, Sandia National Laboratories
C. F. GIBBON, Sandia National Laboratories
NORMAN GOLDSMITH, Staff Scientist, David Sarnoff Research Center, RCA Corporation
BOB LEE GREGORY, Director of Microelectronics, Sandia National Laboratories
RONALD GRONSKY, Senior Staff Scientist and Associate Professor, Lawrence Berkeley Laboratory
D. GRUEN, Materials Sciences Division, Argonne National Laboratory
ROGER HAKEN, Texas Instruments Incorporated
BOB HAMMOND, Los Alamos National Laboratory
T. HARTMAN, Intel Corporation
RICHARD HEESE, Associate Chairman, National Synchrotron Light Source, Brookhaven National Laboratory
DONALD R. HERRIOTT, Senior Technical Advisor, The Perkin-Elmer Corporation
O. WAYNE HOLLAND, Solid-State Division, Oak Ridge National Laboratory
WILLIAM C. HOLTON, Director, Microstructure Sciences, Semiconductor Research Corporation

L. C. IANNIELLO, Deputy Associate Director for Basic Energy Sciences, Office of Energy Research, U.S. Department of Energy

JOSEPH JAKLEVIC, Senior Staff Scientist, Lawrence Berkeley Laboratory

A. WAYNE JOHNSON, Sandia National Laboratories

ROBERT K. JOHNSON, Assistant Deputy Director, Lawrence Berkeley Laboratory

KENNETH JUNGLING, Department of Electrical Engineering and Computer Engineering, University of New Mexico

JAMES R. KEY, Control Data Corporation

RICHARD KIESSIG, Lawrence Livermore National Laboratory

W. J. KITCHEN, Vice-President, Technical Staff, and Director, Bipolar Technical Center, Motorola, Incorporated

COLIN KNIGHT, Advanced Micro-Devices

LARRY A. KOLITO, The SEMI Group, Incorporated

NORMAN KREISMAN, Industry Technology Competitiveness Advisor, Office of Laboratory Management, Office of Field Operations Management, U.S. Department of Energy

SCOTT KREPS, VHSIC Operations, Harris Corporation

RICHARD H. KROPSCHOT, Head, Engineering Division, and Associate Director, Lawrence Berkeley Laboratory

JEFF KUENG, Corporate Solid-State Laboratory, Honeywell Incorporated

G. W. KUSWA, Sandia National Laboratories

ROSS A. LEMONS, Los Alamos National Laboratory

H. J. LEVINSTEIN, Director, VLSI Laboratory, AT&T Bell Laboratories

BERT W. LINDSAY, Albuquerque, New Mexico

DOUGLAS LOWNDES, Solid-State Division, Oak Ridge National Laboratory

JOHN L. LYMAN, Los Alamos National Laboratory

THOMAS C. MAHONEY, Staff Officer, Manufacturing Studies Board, National Research Council

W. MARCUSE, Head, Technology Transfer, Brookhaven National Laboratory

MICHAEL B. MARKS, Assistant Director for Global Technology, Office of Science and Technology Policy

BYRON MARTIN, IBM Corporation

RONALD L. MARTIN, Argonne National Laboratory

P. L. MATTERN, Sandia National Laboratories

GERRY McVAY, Manager, Metals and Ceramics Sciences, Pacific Northwest Laboratory
BRUCE M. McWILLIAMS, LP Program Leader, Lawrence Livermore National Laboratory
MICHAEL E. MICHAEL, Manager, Emerging VHSIC Technology, Advanced Technology Division, Westinghouse Electric Corporation
FRED MITLITSKY, Lawrence Livermore National Laboratory
RULON MONTAGUE, Motorola Incorporated
V. NARAYANAMURTI, Sandia National Laboratories
CONNIE NEUGEBAUER, General Electric Company
BRIAN NEWNAN, Los Alamos National Laboratory
A. S. OBERAI, IBM Corporation
FRANK F. OETTINGER, Chief, Semiconductor Electronics Division, National Bureau of Standards
WILLIAM G. OLDHAM, Director, Electronics Research Laboratory, University of California at Berkeley
KARL E. OLIVER, AFWL-CCN, Kirtland Air Force Base
D. O. PATTERSON, OUSDA (R&AT/CET)
P. S. PEERCY, Sandia National Laboratories
MICHAEL J. PELLIN, Argonne National Laboratory
S. T. PICRAUX, Sandia National Laboratories
KERSTIN B. POLLACK, Director, Program Development, Manufacturing Studies Board, National Research Council
CEDRICK POWELL, Chief, Surface Science Division, National Bureau of Standards
ROD QUINN, Los Alamos National Laboratory
GUY RABBAT, Head, Electrical and Electronics Engineering Department, General Motors Research Laboratories
DONALD F. REILLY, IBM Corporation
DENNIS RICHARDSON, Advanced Technology Division, Westinghouse Electric Corporation
JAMES ROBERTO, Solid-State Division, Oak Ridge National Laboratory
HARRY SAXTON, Sandia National Laboratories
ROBERT SCACE, Deputy Director, Center for Electronics and Electrical Engineering, National Bureau of Standards
D. G. SCHUELER, Sandia National Laboratories
HOWARD R. SHANKS, Group Leader, Semiconductor Physics, Ames Laboratory, Iowa State University
DARRYL L. SMITH, Los Alamos National Laboratory

JON SODERSTROM, Oak Ridge National Laboratory
W. H. SPEECE, Custom Integrated Circuits Division, Harris Corporation
KERMITH SPEIERMAN, Chief Scientist, National Security Agency
JOHN G. STEWART, Vice-President, Corporate Engineering, Applied Materials, Inc.
J. L. STONE, Solar Energy Research Institute
JERRY STRAALSUND, Manager, Materials and Chemical Sciences Center, Pacific Northwest Laboratory
R. H. STULEN, Sandia National Laboratories
LARRY W. SUMNEY, President, Semiconductor Research Corporation
MICHAEL VELLA, Staff Scientist, Lawrence Berkeley Laboratory
FREDERICK L. VOOK, Director, Organization 1100 (Solid-State Sciences), Sandia National Laboratories
HARLAN WATSON, Senate Subcommittee on Energy Research and Development
KENT R. WATTS, AT&T Bell Laboratories
D. L. WEAVER, Sandia National Laboratories
H. T WEAVER, Sandia National Laboratories
EICKE WEBER, Assistant Professor, Lawrence Berkeley Laboratory
PHILIP WEBRE, Principal Analyst, U.S. Congressional Budget Office
KURT H. WEINER, Lawrence Livermore National Laboratory
I. WELBER, Sandia National Laboratories
EDWARD G. WHITAKER, Delco Electronics Corporation
GWYN P. WILLIAMS, Physicist, National Synchrotron Light Source, Brookhaven National Laboratory
A. W. YANOF, Supervisor, X-Ray Technology Group, AT&T Bell Laboratories
J. M. ZEIGLER, Sandia National Laboratories